living planet symposium | BONN 23–27 May 2022

TAKING THE PULSE
OF OUR PLANET FROM SPACE

The science out of CubeMAP

Cubesats for the Monitoring of Atmospheric Processes

Michaela I. Hegglin, on behalf of the CubeMAP SAG
University of Reading, UK | Forschungszentrum Jülich | University of Wuppertal, Germany

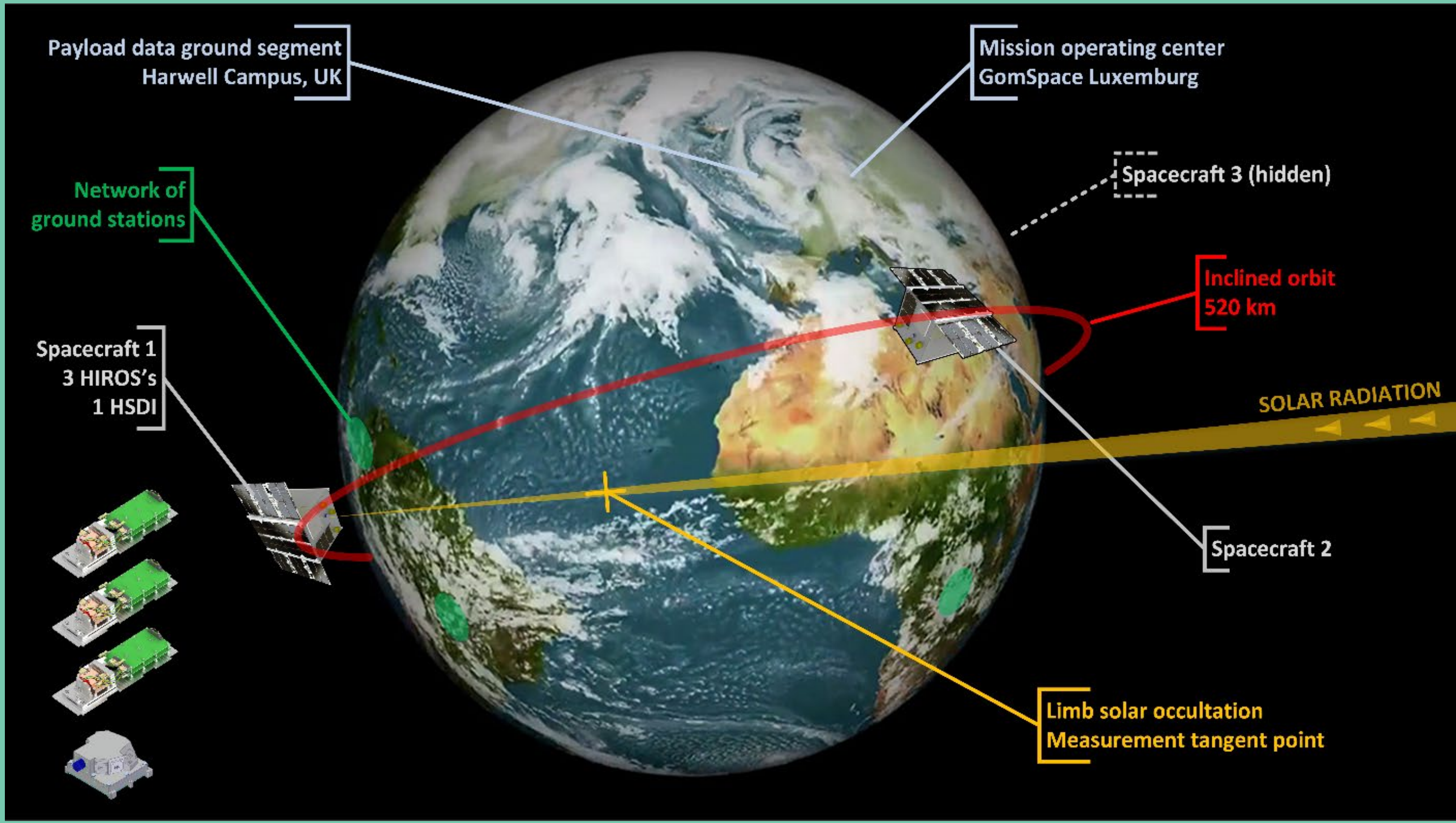
Scout Mission Session – 25 May 2022

SCIENCE ADVISORY GROUP

Michaela Hegglin **(Chair)**	*University of Reading, UK; Forschungsentrum Jülich/University of Wuppertal, Germany*
William Bell	*ECMWF, UK*
Michael Höpfner	*Karlsruhe Institute of Technology, Germany*
Kazuyuki Miyazaki	*NASA Jet Propulsion Laboratory, US*
Christopher Sioris	*Environment and Climate Change Canada, Canada*
Viktoria Sofieva	*Finish Meteorological Institute, Finland*
Susann Tegtmeier	*University of Saskatchewan, Canada*
Damien Weidmann	*STFC Rutherford Appleton Laboratory, UK*
Alex Hoffmann	*European Space Agency*

CubeMAP - Cubesats for the Monitoring of Atmospheric Processes

- New mission concept:
  - Flexible and fast to implement
  - Highly innovative modular system
- Solar Occultation Sounding:
  - "Self-calibrating" (high accuracy)
  - High signal to noise ratio (high precision)
  - High vertical resolution (1-2 km)
- Constellation flying:
  - 3 spacecraft (enhances sampling density)
- Focus region:
  - Upper troposphere and stratosphere (UTS)
  - Tropical and subtropical region
  - Range of GHGs and their isotopologues



DATA PRODUCTS

- Vertically resolved **ozone, water vapour, aerosol,** and long-lived greenhouse gases (CO_2, CH_4, and N_2O)
  - Altitude range 6-50 km
  - Vertical resolution 1-2 km
  - Accuracy 5-10%
- Isotopologues of H_2O (HDO), CH_4 ($\delta^{13}CH_4$) and N_2O ($\delta^{15}N_2O$).
  - Altitude range 6-35 km
  - Vertical resolution 1 km
  - Accuracy 10-20‰
- Modular approach allows for flexibility in choosing the products on new satellites.

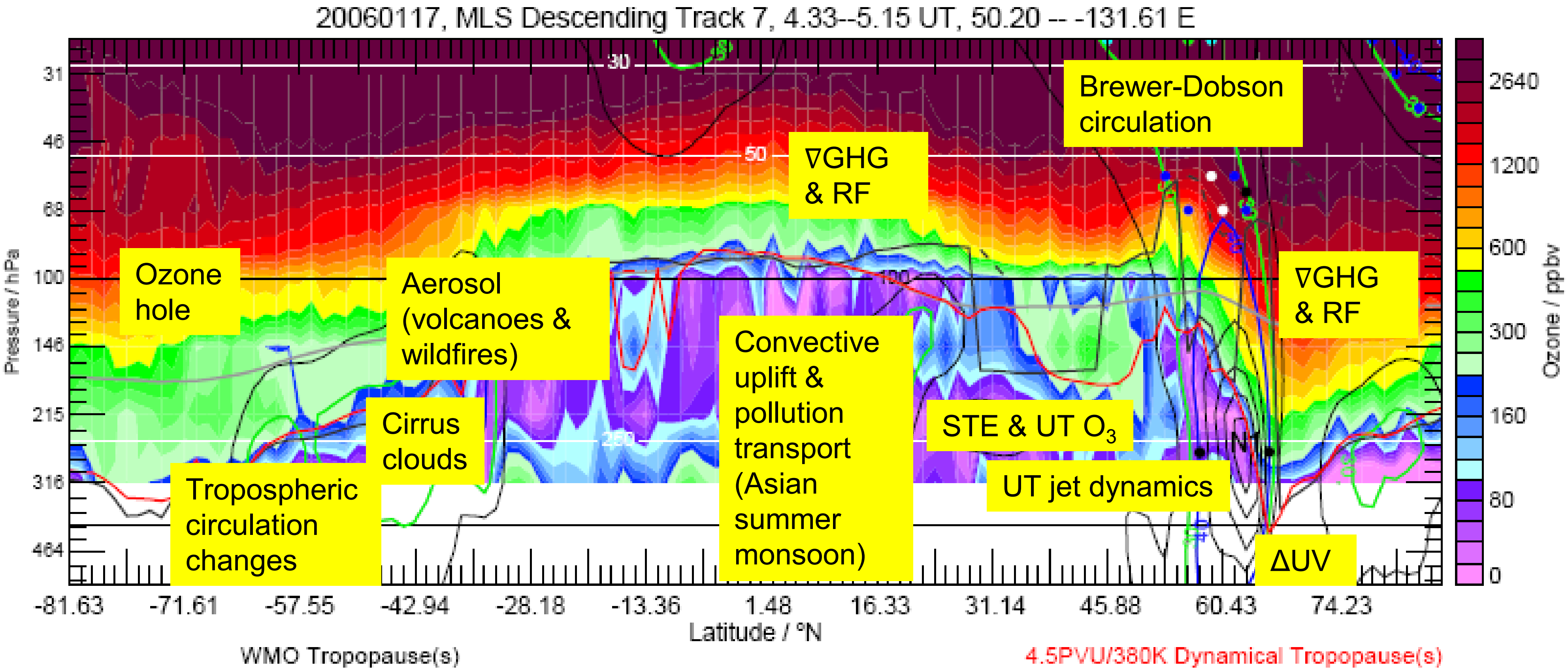
MO	Species	Processes	Alt. Range (km)		Vert. Res. (km)		Accuracy	
			Target	Thres.	Target	Thres.	Target	Thres.
MO1	H2O	Radiative forcing	8-50	12-30	2	5	5%	10%
	HDO	H2O microphys. processes	8-25	12-20	1	3	10%	20%
	H2O	H2O microphys. processes	8-25	12-20	1	3	10%	20%
	CH4	Emissions H2O source	6-50	12-30	2	5	10%	20%
MO2	O3	Radiative forcing	8-50	12-25	2	5	5%	10%
		BDC changes	8-50	12-30	2	5	5%	10%
		STE	8-25	12-25	1	3	5%	10%
MO3	CO2	GHG emissions	6-35	12-20	1	3	5%	10%
	CH4	GHG emissions	6-35	12-20	1	3	5%	10%
	N2O	GHG emissions	6-35	12-20	1	3	5%	10%
MO4	H2O	STE	8-25	12-20	1	3	5%	10%
	O3	STE	8-25	12-20	1	3	10%	20%
	CH4	Emissions Convection	6-25	12-20	1	3	10%	20%
	Aerosol extinction coef.	Emissions Convection	6-25	12-20	1	3	10%	20%
	Aerosol Angstrom exponent	Emissions Convections	6-25	12-20	1	3	30%	50%

MISSION FOCUS

- **Upper troposphere and stratosphere (UTS)**
  - Highly sensitive to climate change
  - Frontier for observations
- **Focus on Tropics**
  - Entry point to the stratosphere
  - Increased surface emissions
  - Convective uplifts (Asian monsoon)

→ Study UTS processes and their response to change

Key dynamical, radiative, and chemical processes



Manney, Hegglin, et al., *ACP 2011*

MISSION OBJECTIVES

MO1 – Quantify water vapour in the UTS to understand its response to changing temperatures and its feedback on climate;

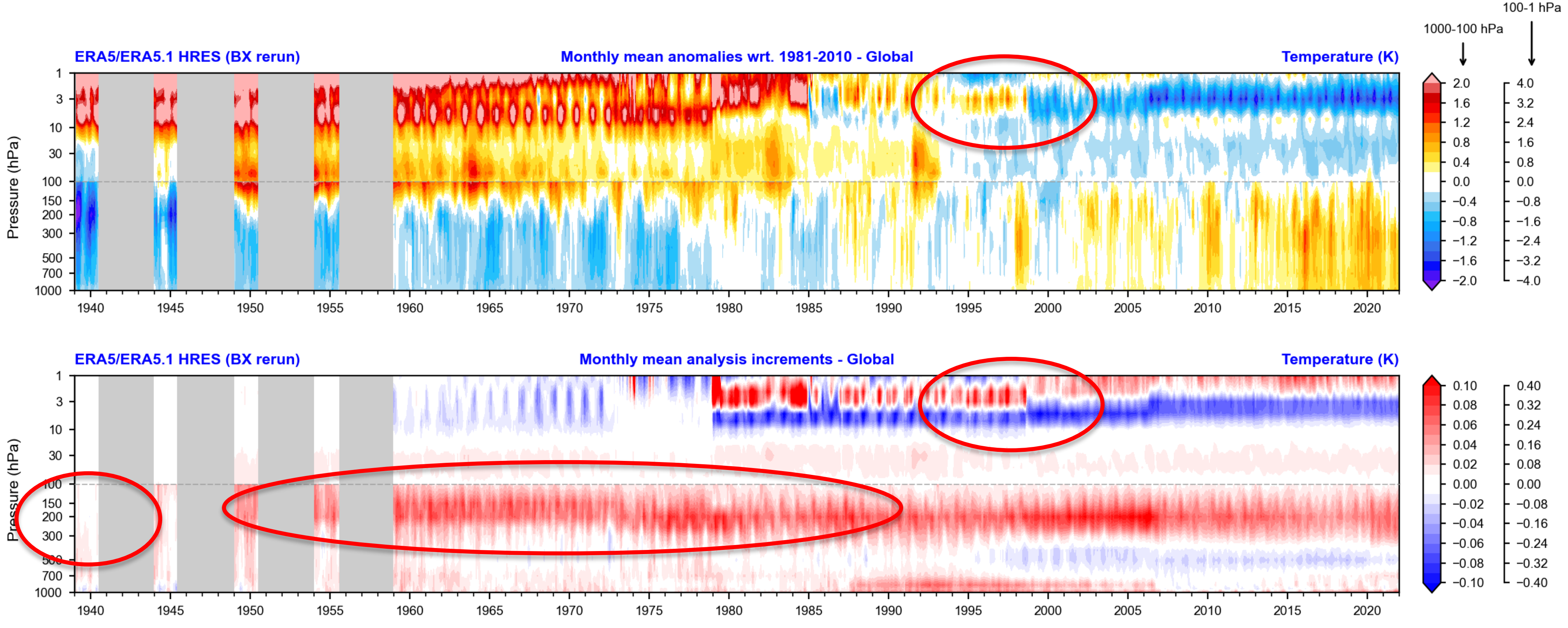
MO2 – Quantitatively study and understand the impact of climate change on stratospheric ozone, and UTS ozone interactions in NWP;

MO3 – Provide an accurate representation of the vertical distribution of UTS GHGs to better constrain regional emission estimates from the nadir sounder infrastructure;

MO4 – Quantify the changing composition of the UTS and its response to increasing anthropogenic and natural emissions.

The impact of model bias on stratospheric temperatures in ERA5

Courtesy Bill Bell, ECMWF



- ERA5 (currently being extended back to 1940) is a widely used reanalysis with 80,000 registered users (and growing)
- Model biases in the stratosphere result in discontinuities in the ERA5 record
  - Partly due to inaccurate representation of H_2O transport processes in the UTLS
  - Partly due to the treatment of methane oxidation

→ CubeMAP will provide an improved understanding of these processes & their representation in the ECMWF system

Copernicus Europe's eyes on Earth | European Commission | ECMWF

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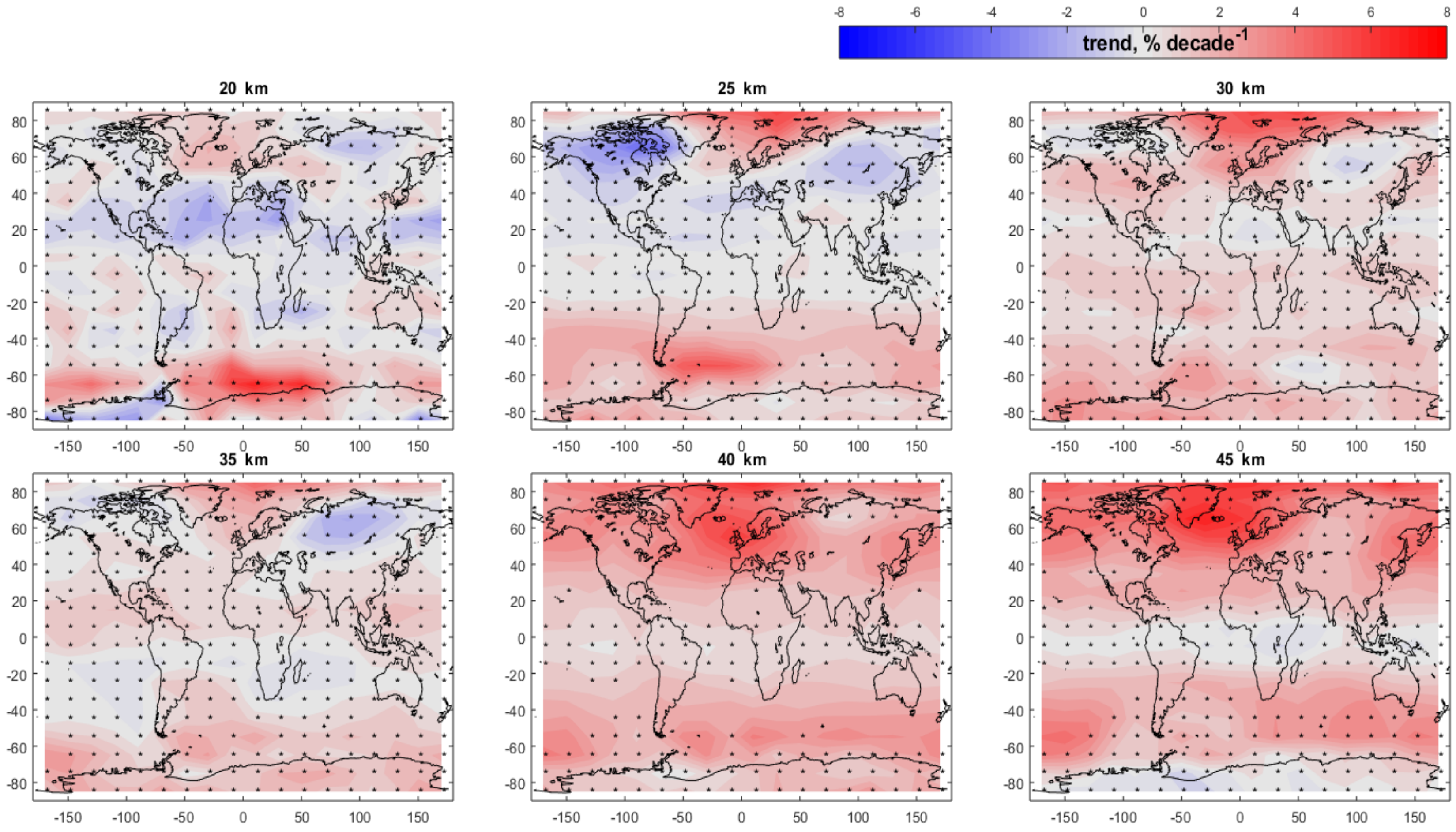
Trends in UTS ozone profiles & open questions

- **Statistically significant trends are observed in the upper stratosphere.**
  - Consistent with previous studies, and also among different datasets and with model simulations
- **New studies found distinct longitudinal structure in ozone trends in the NH.**
  - Trends are particularly large in the UT and LS, and also in polar regions.
  - Drivers are not understood, but are under investigation.



Ozone trends (% decade^{-1}) derived for the period 2003–2018, for six different altitude levels, based on the merged satellite MEGRIDOP dataset. Stars indicate regions where the trends are not statistically significant at the 2σ level. Adapted from ***Sofieva et al.*** *[(2021)]*

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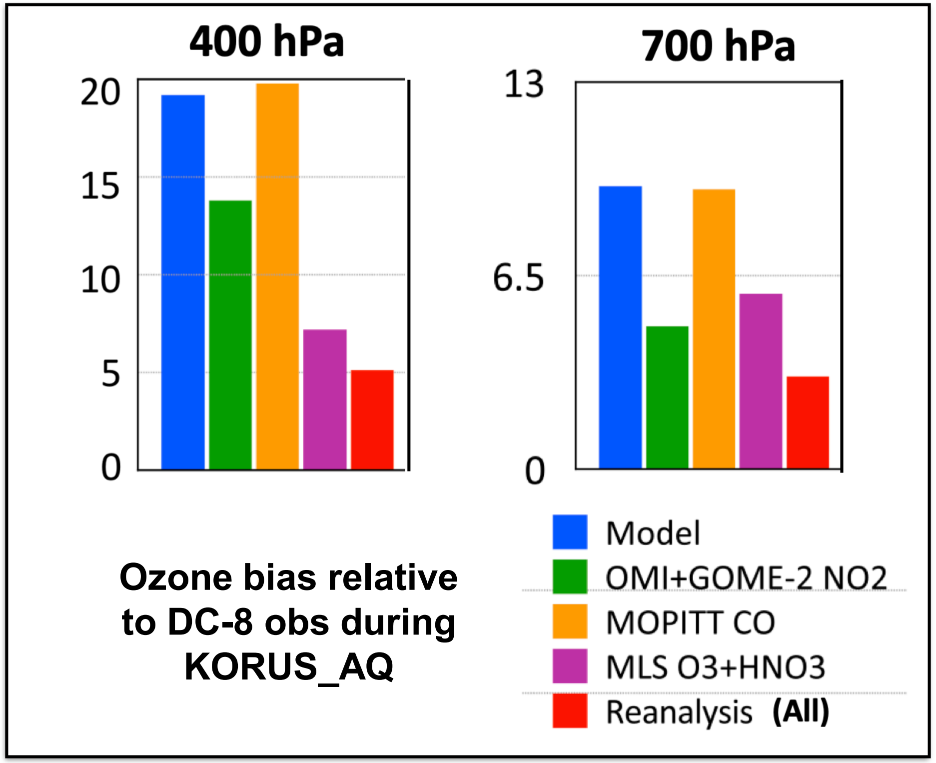
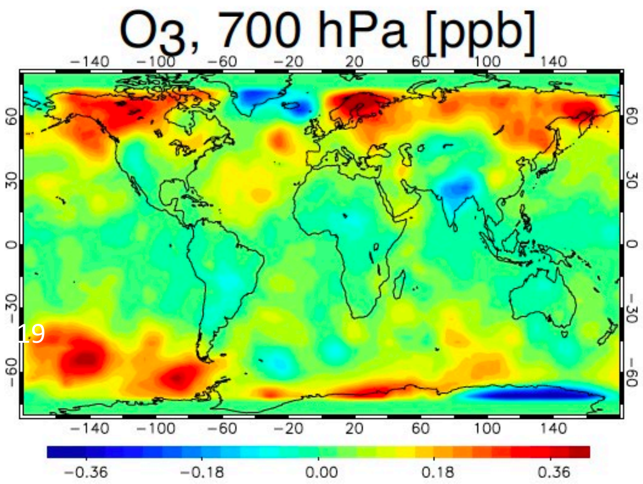
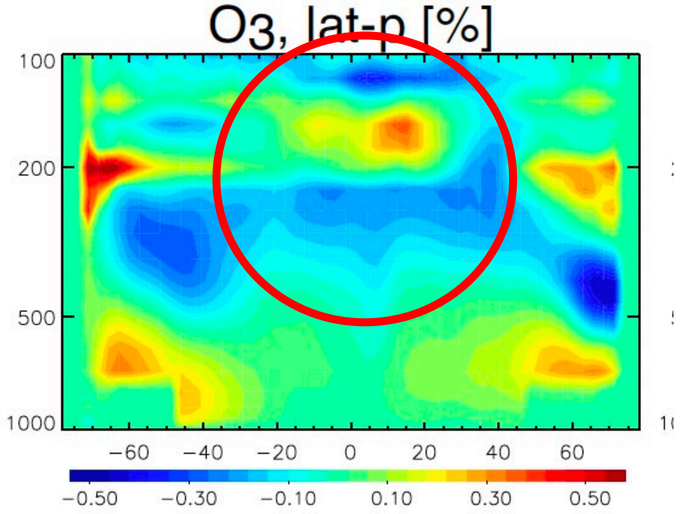
Exploiting nadir & limb synergies using chemical DAS

- The MOMO-Chem chemical reanalysis developed at NASA JPL (**Miyazaki et al., 2020**) has been used to quantify the impact of both individual measurements and combinations of measurements in improving the model performance relative to the “truth.”

Miyazaki et al., JGR 2019







Miyazaki et al., ACP 2012

Analysis increments relative to the zonal mean show large changes in polar regions and upper troposphere in the subtropics and tropics.

- **OMI + GOME-2 NO_2** → Improved the lower tropospheric ozone
- **MLS O_3/HNO_3** → Additional corrections throughout the troposphere.
- **Multi-constituent** → corrects the entire tropospheric ozone profile

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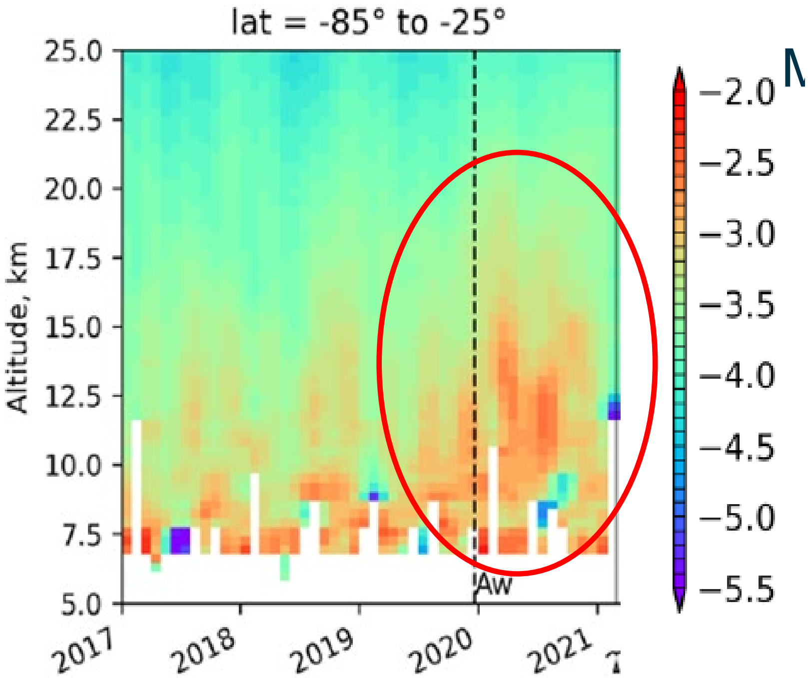
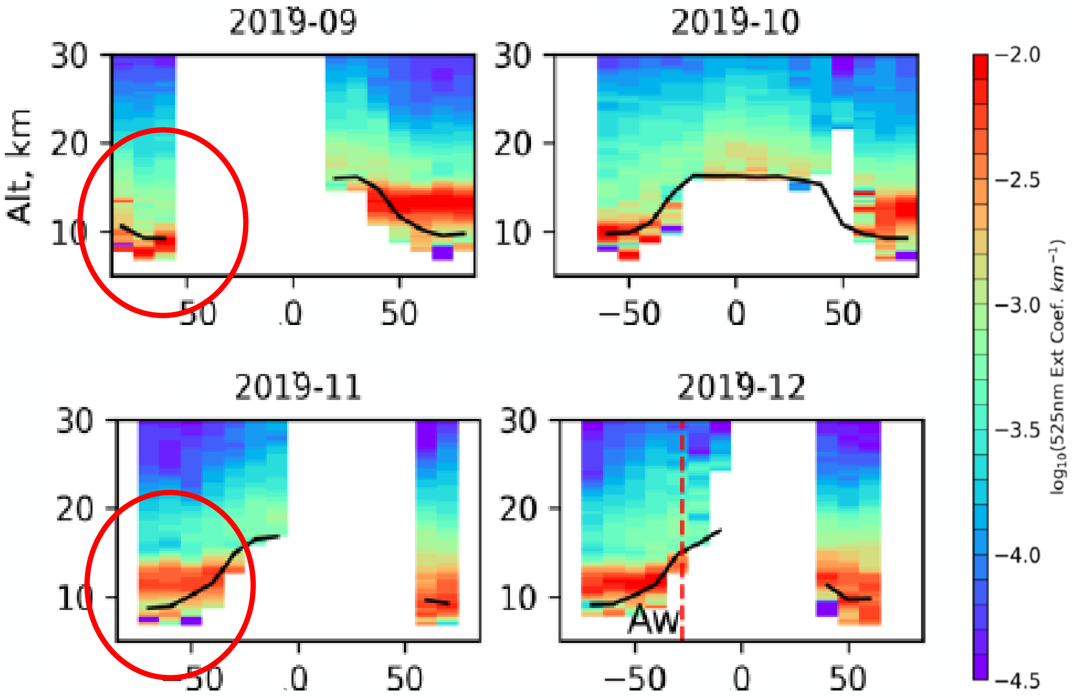
Australian Bushfires 2019-2020

Courtesy of Sujan Khanal
(Univ. of Saskatchewan)

- Climate change is likely to increase wildfire occurrence, which has been found to affect pollution transport into the UTLS, with a potentially strong impact on chemistry, ozone, and radiative forcing.

$\log_{10}$ aerosol extinction coefficient
(km^{-1} at 530 nm)





SCIENTIFIC USER COMMUNITY

- Numerical Weather Prediction (**NWP**) and Reanalyses Centres (ECMWF, European National Meteorological Services)
- Copernicus Climate Change Service (**C3S**) & Copernicus Atmosphere Service (**CAMS**)
- **World Climate Research Programme**
  - WCRP Core Project *Earth System Modelling and Observations (ESMO)*
    → Coupled Model Intercomparison Project (CMIP → AerChemMIP, RFMIP, PDRMIP)
    → IPCC
  - WCRP Core Project *Stratosphere-troposphere Processes and their Role in Climate (SPARC)*
    → SPARC Data Initiative, OCTAV-UTLS, LOTUS, WAVAS, Chemistry-Climate Modelling Initiative (CCMI)
    → WMO/UNEP Scientific Ozone Assessment
  - WCRP Core Project *Global Energy and Water Exchanges (GEWEX)*
  - WCRP Lighthouse Activity *Explaining and Predicting Earth System Change*
- **International Research Community**
  - Climate modelling centers and climate and atmospheric researchers more generally
  - National agencies (inverse modelling, chemical DAS) → **UNFCCC Paris Agreement**
  - Other national activities within NCEO (UK), Transregio TP-change (Germany), …
  - ESA Climate Change Initiative (WV_cci, Ozone_cci, CCI on long-lived GHGs)

SYNERGIES & INTERNATIONAL COOPERATION

- Nadir-viewing measurements (for joint retrievals, chemical data assimilation, and in inverse modelling systems)
  - **Metop-SG A1 and A2** (2023-2030 and 2028-2035)
    - IASI-NG (H_2O, CH_4, CO_2, HNO_3, NO_2, SO_2, NH_3, and CO column measurements, also aerosol and O_3)
    - MWS (tropospheric water vapour, cloud liquid content) / Sentinel 5 (UV-VIS-NIR Instrument)
  - **Copernicus Anthropogenic Carbon Dioxide Monitoring**, **CO2M** (2025)
    - NIR and SWIR (CO_2, NO_2)
  - **GCOM-C3 and GOSAT-GW (JAXA)**
    - Multi-spectral imager (CO_2, CH_4, NO_2)
- EUMETSAT geostationary system 3rd generation
  - **MTG-I1 and MTG-I2** (2020-2029; 2024-2033)
    - IRS (IR-FTS) (water vapour, mid-tropospheric O_3 and CO)
    - Sentinel 4 (aerosol, tropospheric O_3,
- Other limb-viewing instruments
  - **Aura-MLS / ACE-FTS / ACE-MAESTRO / OSIRIS** (all far past their lifetimes!) / **SAGE III/ISS** / **OMPS** (in space)
  - **ALTIUS** (2023 launch) **/ CAIRTS (E11 selection?)**

SUMMARY

- The **UTS chemical composition** is spatially and temporally highly variable and determined by complex processes.
- The tropopause is particularly sensitive to radiative forcing and thus has been dubbed the **canary of the climate system**.
- However, **limitations in current observations**, accurately quantifying UTLS composition variability and trends and identifying their drivers poses a considerable challenge.
- **CubeMAP focusses on addressing this challenge**, putting forward a flexible, fast to implement, and highly innovative modular measurement system, thereby offering an exciting **new science opportunity.**
- **CubeMAP** thereby offers **highly synergistic measurements** to currently flying or planned missions.
- The **science user community** is multi-facetted and works with well-established methodologies, **ready to exploit CubeMAP data products**.

Want to get involved in the CubeMAP user community?

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